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6.3 Drilled shafts

6.3.1 General

Drilled shafts directly support bridge substructure components and sign support structures. In addition to this series of articles the designer should review the design manual articles for specific substructure components and sign supports: abutments [BDM 6.5], piers [BDM 6.6], and sign supports [BDM 10.2, in process].

6.3.1.1 Policy overview

Although the office most commonly supports bridge substructure components on piles, the office recently has begun supporting bridge piers on drilled shafts where drilled shafts are economical and advantageous. In most cases the office does not support abutments on drilled shafts because drilled shafts do not have the lateral flexibility necessary to accommodate the thermal movements of integral abutments. Drilled shafts, however, may be used for abutment support where integral abutments are not feasible.

Drilled shafts are reinforced concrete columns poured in relatively large diameter holes drilled into soil and rock. For support of bridge substructures drilled shafts provide compact foundations that are more likely to fit within divided highway medians and adjacent to existing structures than pile foundations. Drilled shafts can be installed with less noise and vibration than pile foundations, which often is an important consideration for urban sites or sites adjacent to buildings or other structures.

Drilled shafts may function as bridge supports without or with separate footings. Without footings, drilled shafts may simply be extensions of the columns of frame piers. In that situation the drilled shafts should be about 6 inches (150 mm) larger in diameter than the columns. In cases where drilled shafts need to be grouped it is necessary to provide footings as for piles. Closely grouped drilled shafts require consideration of loss of capacity and increased settlement due to group effects.

Although a demonstration shaft typically is required by specifications for a drilled shaft project in order to check the equipment and methods of the contractor, the requirement usually is deleted for experienced contractors. In cases where soil design parameters need to be confirmed, a demonstration or production shaft may be instrumented with an Osterberg Load Cell. The designer should consult with the Soils Design Section and the supervising Section Leader when Osterberg Load Cell instrumentation is required.

Except in unusual conditions the office requires that drilled shafts for bridge support be socketed into rock. For ordinary bridges, drilled shafts may be considered when bedrock is within 40 to 50 feet (12 to 15 m) of the existing ground surface. In the most common design condition, a drilled shaft is designed to carry load by side friction in a rock socket, but if estimated settlements are small, end bearing capacity on bedrock may be added to the side friction capacity. Otherwise, the drilled shaft should be extended into the rock for additional side friction capacity as needed.

Drilled shafts should not be battered because construction of non-vertical drilled shafts is difficult. In cases where lateral loads are large, drilled shafts may be thickened to increase lateral load capacity. If thicker shafts have insufficient lateral load capacity, more shafts should be placed to carry the lateral loads.

Office policy is to reinforce drilled shafts over the full height. The typical reinforcing cage is similar to the cage for a round reinforced concrete column, with equally spaced vertical bars and a spiral. Ties, if used in place of the spiral, are developed with laps rather than hooks so that there are no obstructions within the cage.

Due to lack of redundancy, quality control of drilled shafts is important, and it is necessary to test each drilled shaft used for bridge support. The office requires crosshole sonic log testing, with at least four 2-inch (50-mm) diameter pipes equally spaced inside the reinforcing cage.

The office generally permits use of cased or uncased shafts as appropriate for soil, water, and adjacent structure conditions at the site. Casing is required where soil conditions promote caving, where artesian conditions exist, and where caving would damage adjacent foundations. Also, where drilled shafts are located within close proximity to rail lines the need for and depth of temporary casing shall be investigated.

Uncased shafts may be constructed dry or with slurry depending on soil conditions.

In all cases the designer shall consider existing foundations, utilities, and drainage when locating drilled shafts.

At this time the office has no standard sheets available for drilled shafts used to support bridges.

6.3.1.2 Design information

The soils design package provided for each bridge site by the Soils Design Section contains the soil logs with rock coring information needed for drilled shaft design [BDM 6.1.2], and the preliminary situation plan locates the borings. Although crews make every effort to take borings at drilled shaft locations, on some sites drilled shaft locations will be inaccessible. If the designer needs to interpolate between widely separated borings, the designer should recognize that actual site conditions may require deeper drilled shafts than the interpolation would suggest.

Design of drilled shafts generally shall be in accordance with *Drilled Shafts: Construction Procedures and Design Methods, Publication No. FHWA-IF-99-025* ~~the drilled shaft soils information chart prepared by the Soils Design Section~~ [BDM 6.3.1.5] except as modified in this series of articles. The designer shall consult the Soils Design Section as necessary for additional information and for interpretations of subsurface data.

For specification or construction information beyond the information in this manual and the soils information chart, the designer should consult the following sources. The publications are available from the offices listed and also often are available on the Iowa Department of Transportation web site (http://www.dot.state.ia.us).

- Office of Specifications, “Supplemental Specifications for Concrete Drilled Shaft” (SS-01032)
- Office of Construction, *Construction Manual* and *New Bridge Construction Handbook*

6.3.1.3 Definitions

Reserved

6.3.1.4 Abbreviations and notation

CSL, crosshole sonic logging

6.3.1.5 References

Office of Construction. *Construction Manual.* Ames: Office of Construction, Iowa Department of Transportation, 2006. (Available on the Internet at: http://165.206.203.37/Start_Here.htm)

Office of Specifications. “Supplemental Specifications for Concrete Drilled Shaft” (SS-01032). Ames: Iowa Department of Transportation, Office of Specifications, 2005. (Available on the Internet at: http://165.206.203.37/Start_Here.htm)

O’Neill, M.W. and L.C. Reese. *Drilled Shafts: Construction Procedures and Design Methods, Publication No. FHWA-IF-99-025.* Washington: Federal Highway Administration (FHWA), 1999.

~~Soils Design Section. “Drilled Shaft Foundation Soils Information Chart, English Units” and “Drilled Shaft Foundation Soils Information Chart, Metric Units.” Ames: Iowa Department of Transportation, Office of Design, 1994.~~

Sunday, Wayne and Kyle Frame. *New Bridge Construction Handbook.* Ames: Office of Construction, Iowa Department of Transportation, 2000. (Available on the Internet at: http://www.dot.state.ia.us/construction/bridge_construction_handbook.pdf)

6.3.2 Load application [AASHTO-I 3.8.1]

Loads are transmitted directly to drilled shafts from bridge substructure components such as pier columns and pier footings and from other structures such as sign supports. Live, dead, and other loads transmitted to a drilled shaft shall be determined from the design manual articles for the component or structure supported by the footing as follows: abutments [BDM 6.5.2], piers [BDM 6.6.2], and sign supports [BDM 10.2.2, in process].

For the design of drilled shafts for piers and abutments, live load impact shall be excluded from the vertical loads [AASHTO-I 3.8.1].

In cases where drilled shafts are placed below the water table, loads due to buoyancy shall be considered.

Lateral loads and eccentric loads applied to a bridge substructure component or structure, as well as frame action, will cause shear and moment, and those effects need to be considered in addition to axial loads in the design of the supporting drilled shafts.

6.3.3 Service load groups and application to drilled shafts [AASHTO-I Table 3.22.1A]

In general, drilled shaft load groups and allowable stress increases are given in the AASHTO specifications [AASHTO-I Table 3.22.1A]. Also note the policies for bridge substructure components and structures supported by drilled shafts: abutments [BDM 6.5.3], piers [BDM 6.6.3], and sign supports [BDM 10.2.3, in process].

6.3.4 Analysis and design [AASHTO-I 4.6, 4.13]

The designer may use either the allowable stress design method [AASHTO-I 4.6.5] or the load factor design method [AASHTO-I 4.13] for design of drilled shafts.

The office recommends that the designer use *Drilled Shafts: Construction Procedures and Design Methods, Publication No. FHWA-IF-99-025* as a design guide [BDM 6.3.1.5]. If any of the guidelines contained in the FHWA publication conflict with guidelines in this article [BDM 6.3] or the AASHTO ~~s~~Standard ~~s~~Specifications, the designer shall consult with the supervising Section Leader.

Drilled shafts used as supports for bridge substructure components will be subject to frame action that extends below the ground line. The office prefers that the frame action be considered by means of an iterative solution rather than by arbitrary selection of points of fixity. The designer shall consider the shear and moment caused by frame action in design of both the substructure component and drilled shafts.

If the lateral load at the top of a drilled shaft is greater than the capacity of the shaft, the shaft should be thickened to provide the needed capacity, or additional shafts should be placed and tied together with a footing. Battered shafts are not permissible.

Where drilled shafts are closely spaced to carry vertical or lateral loads, the designer shall investigate the need to reduce capacity of the shafts due to group action [AASHTO-I 4.6.5.2.4, 4.6.5.6.1.4].

A drilled shaft for support of bridge substructure components shall be socketed into rock. The socket should be a depth of at least 1½ shaft diameters and should consider the development length for any reinforcing within the socket length. Generally the drilled shaft design for axial load will be based on the side friction capacity in the socket, but the contribution from end bearing may be added to the side friction capacity under the following two conditions:

- The estimated settlement does not exceed 0.25 inches (6 mm) under service load, and
- The estimated settlement does not exceed 1 inch (25 mm) under ultimate load defined as 2.5 times the service load [AASHTO-I 4.6.5.4].

If either settlement limitation is exceeded, the needed bearing may be obtained by side friction from a deeper socket [OBS MM No. 54].

For enhanced side friction capacity, especially in shale, the designer should consider grooving of the socket.

If permanent or temporary casing is required, the designer shall not consider any side friction capacity over the length of the casing. Permanent casing shall not extend more than 1 foot (300 mm) into rock.

If a drilled shaft that is socketed into rock penetrates consolidating soil layers, the designer shall consider the effect of downdrag.

Minimum drilled shaft diameter shall be 24 inches (610 mm). Larger drilled shaft diameters should be selected in increments of 6 inches (150 mm) [AASHTO-I 4.6.6.1]. Drilled shafts for bridge support shall be at least 36 inches (910 mm) in diameter to accommodate inspection. In cases where the drilled shaft is a direct extension of a bridge column, the diameter of the drilled shaft shall be a minimum of 6 inches (150 mm) larger than the diameter of the column. Preferably the diameter of a drilled shaft should be one of the diameters listed in the soils information chart: 24, 36, 48, or 60 inches (610, 910, 1220, or 1520 mm).

Drilled shafts should be spaced no closer than three diameters center to center [AASHTO-I 4.6.6.4].

The designer shall consider the permissible construction tolerance for the plan position of a drilled shaft. The current supplemental specification for drilled shafts specifies the tolerance as 3 inches (75 mm).

Drilled shaft concrete shall have a strength of 3500 psi (24 MPa), unless the supervising Section Leader approves a higher value.

Drilled shaft reinforcement shall be Grade 60 with a minimum yield strength of 60,000 psi (400 MPa).

Drilled shafts shall be reinforced full height.

6.3.5 Detailing [AASHTO-I 4.6.6.2]

Reinforcement cover, spacing, and development shall meet the AASHTO drilled shaft specifications [AASHTO-I 4.6.6.2].

In drilled shafts used for bridge support, longitudinal bars shall be #8 (#25) or larger. When a large amount of longitudinal steel is required the designer may use bundled bars. Longitudinal reinforcement should be a minimum of eight bars or bundles. The designer should avoid use of double cages. Longitudinal bar splices shall be staggered. The designer shall not splice more than 50% of the bars at any location, and splice locations shall be a minimum of 10 feet (3 m) apart.

The office prefers spiral reinforcing rather than hoops for the reinforcing cage. If hoops are used they shall be anchored with laps rather than hooks to avoid congestion and interference with concrete during placement.

If a drilled shaft is placed with temporary or permanent casing the outside diameter of the rebar cage should be at least 6 inches (150 mm) less than the diameter of the casing to provide for flow of concrete between the cage and hole and to provide for adequate cover.

All drilled shafts for bridge support shall have provisions for crosshole sonic logging (CSL), and the designer shall show on the plans a CSL access pipe layout for each unique drilled shaft. One 2-inch (50-mm) diameter access pipe shall be provided per 1 foot (300 mm) of shaft diameter, but there shall be a minimum of four access pipes per shaft. The access pipes shall be equally spaced around the inside perimeter of the reinforcing cage. The layout should provide adequate space around CSL access pipes for concrete consolidation. The layout should avoid congested areas, especially between column and drilled shaft reinforcing cages and should avoid placing reinforcing bars in a direct line between any two access pipes.